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The Impact of Chemical Protective Clothing on Military Operational Performance

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Wearing chemical protective clothing (CPC) while conducting military operations limits a soldier's dexterity, mobility, command and control, communications, and endurance. A series of field studies was conducted to identify mission degradations from the protective clothing on the chemically contaminated battlefield. The studies differed in complexity but had a common goal of comparing task performance and endurance of soldiers wearing the full protective ensemble versus wearing the standard military field uniform. This article summarizes 3 U.S. Army programs. One of them is called the Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat. A review of 19 studies concerning combat, combat support, and combat service support systems shows that most military tasks can be performed satisfactorily while CPC is worn, but usually, extra time is required to perform such tasks. Higher ambient temperatures and high workloads are especially detrimental to endurance. Realistic training in the ensemble is deemed essential for sustaining performance on the chemically contaminated battlefield.

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Military operations on a chemically contaminated battlefield are likely to present special problems. Soldiers' performance can be degraded by wearing the required chemical protective clothing (CPC) ensemble. The mask and gloves are uncomfortable and compromise manual dexterity, vision, communication, personnel identification, and mobility. Compounding these problems is the potential requirement of wearing the ensemble for several consecutive hours. Another complication is "dual encapsulation," that is, wearing the ensemble while working in a microenvironment such as the turret of a self-propelled howitzer or a closed-hatch battle tank or personnel carrier.

The potential for performance problems was noted in a report entitled "Chemical Warfare: Soldiers Inadequately Equipped and Trained to Conduct Chemical Operations" (U.S. General Accounting Office [GAO], 1991). Partly based on a survey of 93 soldiers to assess whether the standards of chemical training policy were being met, the GAO concluded that the state of U.S. Army chemical training was inadequate for efficient military operations in a chemically contaminated environment. Because of shortcomings in training, problems would be expected in conducting sustained operations and in performing some tasks while the CPC ensemble was worn. In fact, the 1991 Persian Gulf War (Operation Desert Storm) reinforced the need to identify and overcome shortcomings in operational efficiency on the chemically contaminated battlefield.

Knowledge of the protective clothing ensemble's influence on soldier performance is gained from field testing, laboratory studies, and modeling. Field testing, "the conduct of experimentation or the evaluation of manned systems in a credible operational environment" (E. M. Johnson & Baker, 1974, p. 203), serves two important functions:

1. To establish credibility with commanders who must address the practical significance of the results. (Studies that employ scenarios consistent with how one will fight are more apt to be taken seriously by commanders.)
2. To identify deficiencies from realistic scenarios to help develop new doctrinal, organizational, leadership techniques, training, and matériel improvements. Whether such changes foster efficient operations on the battlefield can be verified in subsequent studies.

Three major programs investigate chemical defense issues through the use of field studies. The common focus is to examine the effects of wearing the full CPC ensemble (Mission-Oriented Protective Posture Level IV [MOPP IV]) versus the Battle Dress Uniform (BDU) on task performance (time and accuracy measures) in a variety of military scenarios. These programs are Joint Chemical Biological Contact Point and Test (Project DO49), Combined Arms in a Nuclear/Chemical Environment (CANE), and Physiological and Psychological Effects of Nuclear,

Biological, and Chemical (NBC) and Extended Operations on Systems in Combat (P^2NBC^2).

Test results from these programs are used to develop guides for commanders and to influence the development of soldier clothing, equipment, and computer models that predict soldier performance and soldier well-being. The following sections outline the methodologies of the programs, summarize their key results, discuss the applications of the findings to soldier performance issues, and note constraints in interpretation of data from these types of field studies.

SUMMARY OF PROGRAM RESULTS AND APPLICATIONS

DO49

DO49 sponsors small scale, controlled field scenario tests that examine team performance of specific military tasks while soldiers wear U.S. military chemical protective ensembles. Examples of tasks were removal and replacement of an M60 tank power pack and transmission, repair of an M60 machine gun and an electronic circuit board, installation and tear-down of radio-teletype equipment, unloading and loading a HAWK antiaircraft missile, and infantry-route reconnaissance operations (Davis, Wick, Salvi, & Kash, 1990).

Results. In general, all military tasks tested could be accomplished in MOPP IV, but the time to complete tasks was often increased compared to the time to do them without wearing the ensemble.

Davis et al. (1990) summarized the operational task data from these DO49 experiments, as well as a series of Air Force chemical defense studies, by classifying the distribution of performance decrement factors (PDFs) from 756 tasks. (PDF is the time to complete a task in MOPP IV divided by the time to complete it in BDU.) The bimodal nature of the distribution suggested classifying the PDFs into a lower end of "not degraded" with a mean of 1.0 (range = 0.00–1.15), a middle "slightly degraded" area with a mean of 1.5 (range = 1.16–1.85), and an upper "moderately degraded" end with PDFs greater than 1.85. Twenty-one percent of the tasks fell in the not degraded category, 69% fell in the slightly degraded category, and 10% fell in the moderately degraded category.

Davis et al. (1990) then classified each task by the ability required to perform it. Using a 10-item taxonomy, Davis et al. differentiated outcomes based on the distribution of PDFs: Most tasks requiring communication, manual control skills, movement and coordination skills, or visual pattern skills had a slightly degraded PDF (1.16–1.85). For the 10% of tasks that fell within the upper end, moderately

degraded zone (>1.85), precision control, manual control, and movement skills were most frequently associated with degradation. As an example, M109 breech block reassembly subtasks, requiring precision control skills, were associated with higher end PDFs.

Applications. In these small-scale, focused military scenarios conducted in relatively low-stress environments (except for some heat-load trials), all tasks could be performed by soldiers wearing the full ensemble, with 10% of the tasks moderately degraded as rated by Davis et al. (1990). Categorizing of task performance into zones and cross classification of the tasks by the abilities required to perform them provides a convenient means by which to estimate degradations of other tasks by their similarity of action or abilities. This PDF information functions as a guide for military commanders to estimate troop performance degradation for different tasks, abilities, or simple scenarios. Knowledge of the upper end PDFs allows pinpointing tasks or abilities likely to be affected while CPC is worn and leads to recommendations for focused training. The data also serve as inputs to predictive operations research models such as the Army Unit Resiliency Analysis (Sheroke & Klopcic, 1991) and wargaming models such as JANUS (U.S. Army TRADOC Analysis Command, 1992).

Methodology issue. In an extensive review of chemical defense studies, Taylor and Orlansky (1991, 1993) noted that training on these DO49 tasks in BDU typically was not conducted to stable baseline levels before formal testing of the treatment, that is, wearing of the full protective ensemble. Performance improved over trials, but assessment and interpretation of the exact contribution of protective clothing at MOPP IV to a decrement from BDU was often confounded by practice effects in each clothing condition. Assuming the practice effect is greater in the BDU condition, the lack of proper training before a study would likely lead to misleading estimations of the true impact of protective clothing on performance.

CANE

CANE involved large scale, tactical scenarios with both friendly and enemy units for durations up to 96 hr. Weapon systems were instrumented to collect data on direct fire events, which made real-time casualty assessment possible. Other measures of performance included time to complete specified tasks and subjective evaluations of their correctness and degree of completion. CANE was run in phases (I, IIA, IIB, and Close Combat Light), with each phase dealing with a different focus.

Phase I: Infantry platoons. The test plan for Phase I called for eight 40-man infantry platoons to participate in a 72-hr scenario of offensive and defensive operations in a baseline condition (BDU) and in a *simulated* nuclear–chemical environment, which included a 12-hr MOPP IV scenario on Day 2. The order of BDU and MOPP IV was varied to minimize the learning effects. Performance measures focused on aspects of leadership, communication, and combat efficiency and involved comparing the percent change of MOPP IV scores from baseline scores.

Key findings (Draper & Lombardi, 1986) were as follows:

1. *Command and control.* Two conclusions were reached: (a) Command and control (i.e., soldier performance at planning, directing, coordinating, and controlling forces and operations) degraded because of exhaustion of leaders, changes in leader attitudes (increased frustration, irritation, and impatience), and disorientation (land navigation problems); for example, when platoon leaders became simulated casualties, the next senior soldier properly assumed command less than 25% of the time, in part because of a lack of awareness that the leader had become a casualty; and (b) correct identification of leaders and other personnel was difficult in full MOPP IV, in part because the NBC masks cover the face and the overgarments had few identifiable markings (name tag and rank insignia).
2. *Communications.* Because of difficulty in understanding verbalizations through the mask and hood: (a) the number of radio calls increased, and (b) time spent on radio communications increased (e.g., 71% of calls for indirect fire were completed within 10 sec with BDU, but only 50% were completed as quickly with MOPP IV).
3. *Combat efficiency.* Four conclusions were reached: (a) Time to complete a mechanized infantry attack increased (37 min with MOPP IV vs. 20 min with BDU); (b) in general, engagement efficiency (hits plus near hits divided by shots fired) decreased with all weapon types; (c) acquiring and identifying targets were more difficult because of the reduced field of view when wearing the protective mask; and (d) reduced field of view and recognition problems contributed to a 20% fratricide rate from small arms fire, compared to 4% with BDU.

Phase IIA: Tank company teams. Each of two tank company teams with supporting elements engaged in two operations of 72 hr, one in baseline and one in a simulated nuclear–chemical environment (Mojecki et al., 1987). Each operation included three movements to contact, three attacks, and four defensive engagements. The 2nd day in the nuclear–chemical environment involved 12 hr continuously spent in MOPP IV. Comparison of the MOPP IV to baseline results on this day showed the following: (a) Seventy-four percent fewer targets were destroyed in attack mode, and 80% were destroyed in defensive mode; (b) effectiveness of

antitank rounds (tank gun and missiles), as measured by kills per rounds fired, was decreased 60% in attack and 65% in defense; (c) attacks took 33% longer to conduct; (d) engagement of targets was 50% lower; and (e) the loss–exchange ratio (number of friendly vehicles destroyed compared to number of enemy targets destroyed) was 4.6 times higher in offensive engagements and 5.5 times greater in defensive engagement.

Phase IIB: Battalion level. In this test, two battalion task forces each engaged in two operational scenarios of 96 hr, one in BDU and the other in a simulated nuclear–chemical environment (U.S. Army Chemical School, 1989). Soldiers wore MOPP IV during each of 10 engagements in each operation (4 day attacks, 4 day defenses, and 2 night defenses). Results showed that, during attacks, battle synchronization was degraded while in MOPP IV compared to BDU because commanders had difficulty controlling the location of units, timing of operations, and maneuvering their forces. A main cause of these deficits was the scout units' difficulty in locating and reporting enemy positions because of the degradation in hearing, seeing, and communicating caused by the MOPP IV. As a result, engagements with enemy units were closer than desired and were characterized by fewer primary weapon rounds fired, fewer targets destroyed, and reduced survival of infantry fighting vehicles. During defensive engagements, a notable deficiency was a 95% increase in time to move to alternate battle positions, and scout operations were again degraded, leading to poor battle outcomes. Significant deficiencies in the performance of combat support and combat service support duties were also reported.

Close combat light. This phase involved each of three light infantry companies participating in separate 96-hr baseline (BDU) and 96-hr nuclear–chemical environment operations characterized by three night attacks and one day-long defensive engagement (U.S. Army Chemical School, 1993). In the latter operation, soldiers wore MOPP IV during all battles or about 6 hr per day. Key results were as follows:

1. Close combat light units in MOPP IV traveled more slowly, taking 36% longer than in BDU to reach the objective. They were also less effective in operating direct-fire weapons because of visual and hearing problems and the difficulty in using night-vision devices while wearing the protective mask.
2. Leaders experienced marked performance degradation. For example, they did not execute plans as effectively in the simulated chemically contaminated battlefield, they micromanaged and delegated less, and they slept less and were more fatigued.

3. The units' radio communications degraded because of the mask and hood, resulting in a 28% increase in the number of repetitions and clarifications of messages.

4. Fire support operations were degraded. For example, more grid location and gun setting errors occurred, fewer rounds were fired, and fire mission times were slower. The report noted the advantage of training under simulated chemical conditions to learn how to adjust to the unique environment. In doing so, the number of enemy vehicles "destroyed" increased over days, and the degradation in mission execution times for howitzer crews disappeared by the fourth day of the nuclear–chemical environment condition.

Applications. The four CANE phases summarized here show degradation in combat efficiency, command and control, and communications. Although most tasks could be completed in MOPP IV, they often took more time, and accuracy was often degraded. An important function of the CANE program was to assist in fixing deficiencies identified in CANE studies. Based on consistent results from all the CANE phases, leadership training for personnel involved in chemical operations and enhancement of command and control operations while MOPP IV is worn were judged to be critical items requiring improvement. These areas especially are being examined for ways to compensate for the impact of MOPP IV on operations and thereby improve chemical warfighting capability under NBC conditions.

Design and methodology issues. The changes in key performance measures should be considered within the context of these types of field studies. Because of the need to gain information under realistic battlefield conditions, CANE involved free-play, large-scale scenarios. Although large amounts of data were gathered by observers and instrumentation, the absence of a true design places some caution on result interpretation. Certain aspects of E. M. Johnson and Baker's (1974) extended definition of field testing apply here: "[Field testing] addresses real but messy problems; involves a lack of control over the conduct of the test; has multiple objectives; requires an eclectic methodological approach; [and] almost always involves a value judgement" (p. 212). The latter point is important in that, in Phase I, not all evaluators were experienced enough to provide quality subjective judgements of platoon activities (Draper & Lombardi, 1986). Also, Phase I was characterized by severe weather and data collection problems that limited usable data to only five of the eight platoons. In fact, failures in instrumented data collection occurred in each CANE phase (e.g., during Phase IIB, data on two attacks and two defenses were lost). All phases were characterized by relatively small sample sizes because of cost considerations. Data collector and evaluator fatigue was noted in Phase IIA. The worthiness of these multiple phase CANE results is

the *repeated* demonstration of operational deficiencies in task performance during realistically scaled and conducted engagements.

P²NBC²

This program represents a "middle ground" between DO49 and CANE of more controlled scenarios involving specific military systems and the performance of military crews who operate them. Full encapsulation in MOPP IV, hot ambient environments, extended workdays (sometimes 24 hr or longer), and operations at night represent some of the typical stressors encountered in P²NBC² studies. In addition to time and accuracy measures, psychological and human factors data were collected from interviews and test batteries administered periodically during a study.

Studies looked at the capability of Army units to perform combat, combat support, and combat service support operations. Examples of units studied include armor, artillery, mechanized infantry, NBC reconnaissance, air ambulance, battalion aid station, air defense, signal, aviation, smoke generation (used for obscuring, screening, or marking), decontamination, and maintenance. Results from the 19 P²NBC² field studies conducted between 1985 and 1994 are summarized next (for more details on the scenarios, temperature conditions, training, and main dependent variables, see Headley & Cunningham, 1995).

Results—Endurance. Operating on the chemically contaminated battlefield requires great stamina. Reduced troop strengths will preclude quick or frequent replacement of crews. Hence, all soldiers must be capable of conducting operations for extended periods, and casualties must be kept to a minimum.

The P²NBC² studies documented the effects of high ambient heat on soldiers wearing the full CPC ensemble during full field operations. Some examples of endurance problems are as follows:

1. NBC reconnaissance teams had difficulty completing 4.5-hr missions in ambient temperatures ranging from 75 to 95 °F (24–35 °C; Jarboe & Troutman, 1990).
2. M109 (self-propelled howitzer) crews could sustain firing missions for only 2 to 4 hr in approximately 90 °F (32 °C) temperatures (Headley, Brecht-Clark, & Whittenburg, 1989). In slightly milder temperatures, two M109 crews lasted only 1.5 to 2 hr, whereas a third crew completed its mission after 3.5 hr, but in unseasonably cool conditions (Zubal et al., 1993). Towed artillery crews were able to endure about 4 hr under conditions of relatively higher workload and mild ambient temperatures (74–81 °F [23–27 °C]; Zubal, Doss, & Thompson, 1996).
3. The endurance of armor crews ranged from 3.3 to 16.6 hr in 48-hr scenarios (Headley, Brecht-Clark, Feng, & Whittenburg, 1988).

4. Soldiers performing high physical workloads were particularly susceptible to becoming casualties, as witnessed by the dropouts in studies that focused on vehicle decontamination (Blewett et al., 1992; Blewett, Seitzinger, Redmond, Fatkin, & Banderet, 1993), smoke generation (Blewett, Ramos, Redmond, & Fatkin, 1993), and combination smoke generation-and-decontamination duties (Blewett, Redmond, Modrow, Fatkin, & Hudgens, 1994). The Blewett, Ramos, et al. study showed that endurance for as long as 6 hr is unlikely and that the ability to perform operations for long periods using a manual fog oil pump is decremented because of heat stress.

5. Seven of 12 patient-decontamination team members were withdrawn after about 2 hr during the study's hottest trial, which reached a high of 96 °F (36 °C; Blewett, von Fahnestock, et al., 1995).

Results—Performance. For the tasks and scenarios studied, several shortcomings of crews performing in MOPP IV compared to BDU were identified. Artillery crews required longer times to fire rounds (Headley et al., 1989; Zubal et al., 1993; Zubal et al., 1996). Difficulties in performing artillery operations were attributed to visual, dexterity, and bulk restrictions from the ensemble (Headley et al., 1989; Zubal et al., 1993). Air defense teams required that enemy aircraft be closer for detection and identification (D. M. Johnson & Silver, 1992, 1993). Installation tasks pertaining to mobile subscriber communications equipment took twice as long, and voice transmission of messages took 50% longer (Blewett, Redmond, Ramirez, & Harrah, 1993). Expected rates for processing contaminated patients at a battalion aid station were not met; for example, a maximum of 8 versus the standard 20 patients were processed per hour (Blewett, Arca, Stickel, Jones, & Rowan, 1990).

Some tasks in MOPP IV were accomplished without significant decrement on either time or accuracy measures, as exemplified by studies of mechanized infantry crews (Headley et al., 1988), smoke generation (Blewett, Ramos, et al., 1993), vehicle decontamination (Blewett et al., 1992; Blewett, Seitzinger, et al., 1993), litter-patient decontamination and helicopter rearming (Blewett, Ramos, et al., 1994), corps hospital decontamination operations (Blewett, Arca, et al., 1995), and armor combat service support operations (Perez & Chaudoin, 1990). Most of the tasks in these studies mainly involved gross motor skills as opposed to fine motor control (e.g., mount and dismount vehicle, perform tactical movements, operate manual pump, spray decontaminant onto a vehicle, carry a patient on a litter, cut contaminated clothes off patients, load a missile into the launch tube of a helicopter, and conduct combat resupply operations). In the Blewett et al. (1992) study, although desired processing rates for vehicle decontamination were met, the quality of task performance degraded due to incomplete vehicle decontamination.

The P^2NBC^2 studies strongly suggest that performance in the ensemble can be influenced by the following conditions and their interactions: the type of task

involved, the level of metabolic energy expenditure, soldier fatigue when wearing the protective ensemble, acclimatization to high ambient temperatures, the ambient temperature and relative humidity, adherence to drinking water discipline, prior training time in MOPP IV, and time required to operate in MOPP IV (if the soldier does not know the duration the ensemble must be worn, additional psychological stress results). Knowledge and understanding of these variables have greatly influenced military doctrine, training, and matériel enhancements. Such influences are discussed in the Applications subsection that follows.

Results—Stress assessment. An understanding of the stress inherent in chemical defense scenarios may help to identify ways for soldiers to cope and endure longer and to achieve more acceptable levels of performance. A self-report stress assessment battery was implemented in recent P^2NBC^2 studies (e.g., Blewett, Ramos, et al., 1993; Blewett, Ramos, et al., 1994; Blewett, Redmond, et al., 1994). The degree of stress experienced by soldiers in the tests was assessed from responses to four short questionnaires administered before, during, and after the scenarios. Responses were evaluated by comparing them with data from referent norms that represent low, medium, and high levels of stress (for a description of the battery as well as administering and scoring procedures, see Hudgens, Malkin, & Fatkin, 1992).

As an example, the sensitivity of the battery to P^2NBC^2 field test conditions is demonstrated by a recent study (Blewett, Ramos, et al., 1994) with soldiers in MOPP IV conducting litter-patient decontamination procedures. The study was conducted on 4 summer days during which the ambient test conditions (mean wet bulb temperatures) were as follows: Day 1, 83.3 °F (29 °C); Day 2, 74.4 °F (24 °C); Day 3, 74.3 °F (24 °C); and Day 4, 74.5 °F (24 °C). Self-report stress perception measures were obtained 5 times each day. A significant correlation was found between negative affect scores and wet bulb temperatures obtained over the 20 measurement times (Pearson $r = .73$, $p < .001$). The sizes of the mean negative affect scores placed the soldiers' responses on the hottest day in the range of moderate stress relative to referent norm conditions, whereas their responses were not different from the no-stress referent protocol on the cooler days.

The stress battery is quick, noninvasive, inexpensive to administer and represents a fruitful source of data directly from the soldier. Quantifying the soldiers' stress perceptions provides a method of determining whether vulnerability to stress is a component of observed performance degradation.

Applications. As stated in its charter (Department of the Army, 1987), the P^2NBC^2 program was to

> provide planning and [identification of] operational risk factors to field commanders, to support development of training programs, to develop doctrine and organization, and to influence the design and acquisition of materiel to improve the capability to

conduct successful combat operations on a battlefield where NBC weapons are extensively and continuously employed. (p. 1)

Some changes in Army *doctrine* might help to reduce certain adverse effects of MOPP IV and to maintain a minimum safe defensive posture for the current conditions and threat (Stokes & Banderet, 1997/this issue). The revised Army Field Manual on NBC protection (FM 3–4; Department of the Army, 1992) provides guidance for flexibility in U.S. Army MOPP policies. Operating in a MOPP III status (gloves carried, overgarment opened) would mean improved manual dexterity and less need for rest breaks because of buildup of body heat. For example, the mobile subscriber system operations would likely have resulted in less task time decrement if the scenario allowed a MOPP III status (Blewett, Redmond, et al., 1993). P^2NBC^2 results led to a doctrinal recommendation of using low hover and land-and-load techniques versus hoisting methods in air ambulance operations because of low contamination transfer and quicker evacuation times (Blewett, Jones, & Arca, 1991).

The importance of *training* is also made clear by the P^2NBC^2 results. The GAO report (U.S. GAO, 1991) noted that not enough emphasis was given to training in MOPP to prepare soldiers for operations on the contaminated battlefield. A beneficial experience-in-MOPP factor was seen in the D. M. Johnson and Silver (1993) Stinger air defense artillery study. Practice improves speed and accuracy in performing military duties, but characteristics of the ensemble degrade time to perform many tasks. Proper training in MOPP can be important in other ways to enhance performance. Depending on the type of task or skills required to perform a job, improvising to facilitate performance is often necessary, such as learning to use a pencil to press keys or attaching name tags on the backs of ensembles for identification purposes. As noted by Headley et al. (1989), it is important that soldiers learn "how to conduct business" (p. 514) in MOPP before the protective ensemble must be worn for operations. Once soldiers learn they can operate in the ensemble, its annoying features become less important to the wearer and interfere less with performance.

The P^2NBC^2 data suggest that *endurance* can be increased by adherence to the guidance in FM 3–4 concerning work–rest periods and water requirements, as functions of ambient temperature, MOPP level, and physical work rate. Examples of this are mechanized infantry crews who completed a 60-hr, multitask scenario by taking reduced MOPP status breaks every 6 hr (Headley et al., 1988), and corps hospital decontamination teams working in shade, taking hourly rest breaks and a lunch break, and observing water discipline (Blewett, Arca, et al., 1995). The solution of portable personal cooling systems offers promise as shown in the Blewett, Ramos, et al. (1994) study, although issues of weight, comfort, fit, and equipment noise remain to be solved. The Jarboe and Troutman (1990) study demonstrated the importance of an adequately cooled vehicle to permit sustained

operations. P^2NBC^2 data have been aggregated and applied to models that provide reliable prediction of heat strain. These models and tactical decision aids (e.g., P^2NBC^2 Heat Strain Decision Aid; McNally & Berndt, 1993) are also being reviewed by NATO allies for use by their forces.

Design and methodology issues. Results from the P^2NBC^2 studies must be evaluated in context of scenario constraints (Headley et al., 1989): (a) Typically, the duration of the scenario is known to the test participants; (b) participants are volunteers who have signed informed consent statements and are free to withdraw from the scenario at any time; and (c) the performance imperatives of real battle are missing—there was no live fire, the "contaminated" battlefield was simulated, and true sights, sounds, fear, and battle fatigue were missing. However, although the study scenarios do fall short of actual combat, performance effects were found.

The field studies were conducted under a variety of study designs, weather conditions, training on tasks, and adaptation time to the protective ensemble. Within a given study, differences in temperature, training, and experience could limit MOPP comparisons: Ambient temperatures for crews in BDU were sometimes different for those tested in MOPP IV. Inadequately trained crews yielded MOPP effects that were influenced by learning effects. Also, for some soldiers, participation in a study was the first real experience with chemical defense gear. To minimize many of these confounding effects, crews should be trained to predefined skill levels in BDU, and multiple trials should be investigated to look at performance changes over time (see Taylor & Orlansky, 1993).

In some studies, the experimental designs only resulted in descriptive statistics rather than parametric statistics, thereby limiting interpretation and generality of the data. Additional limitations also resulted because costs necessitated relatively small numbers of trials and sample sizes.

DISCUSSION

Wearing CPC as a defensive posture during chemical warfare can lead to soldier performance and endurance problems. All aspects of the ensemble are potential causes of deficiencies in mission capability. Forcing soldiers into MOPP IV produces problems in command and control, communication, and tasks requiring fine motor coordination. Time to complete many tasks is increased, and depending on temperature and workload, the duration of safe operations may be decreased.

Studies from the DO49 project showed that speed–accuracy trade-offs are usually made by soldiers in MOPP IV who achieve accuracy at the expense of completion time. Sixty-nine percent of tasks fell within the "slightly degraded" category, and given that the average performance decrement factor was 1.5, this

value might be construed as a general degradation factor for these kinds of tasks. The U.S. Army's CANE program noted soldier difficulties not only in combat efficiency (both attack and defensive operations) but also in command and control, communication, and identification. The P^2NBC^2 program found many deficiencies in the ability of crews to perform system-specific tasks during a variety of operational conditions. If time to perform a task is not critical, then ensemble-induced increases are not likely to be militarily significant if the task can be performed to standard. However, many scenarios will not allow delayed reaction, such as for field artillery support, direct armor fire, vehicle decontamination procedures (slow processing times can lead to queue buildup), and command and control operations. Thus, although most tasks can be performed while wearing MOPP IV, maintaining accuracy at the expense of time is not always tolerable.

Clearly, sustained military operations during stressful ambient heat or under high workload will be problematic. Leadership will be an important factor in endurance by enforcing appropriate drinking water discipline, work–rest cycles, and crew rotations (cross training). A key finding, common to all the studies, is that training in MOPP IV for extended periods allows the soldier to acclimate and develop behavioral compensations that will extend endurance. This is a central message to commanders from the efforts of these programs. Experiencing the potentially degrading factors of the protective clothing ensemble and learning how to perform tasks in it can reduce some of the deficits. Because the contaminated battlefield is a likely future battlefield condition, training in MOPP IV is as essential as training during similarly adverse conditions of darkness or bad weather. Leaders should instill the confidence in their soldiers that they can survive and fight to win on the chemical battlefield. Increased training in MOPP IV will reinforce this confidence and improve task performance and endurance in this full protective ensemble.

However, a fuller understanding of the impacts of stress, motivation, and adaptation is needed to increase endurance of the individual soldier in MOPP IV. One issue is that of predicting which individuals are susceptible to heat stress while wearing CPC. Another issue is the apparent importance of psychological factors relating to the casualty phenomenon in many P^2NBC^2 field studies. Review of several recent studies (Redmond, 1993) indicates most casualties (both self-withdrawals and physician-directed withdrawals) occur before participants exceed physiological safety criteria (e.g., a participant is to be immediately withdrawn if core body temperature reaches 103 °F [39 °C]). Psychological data indicate significantly higher perceptions of stress for casualties than for those who do not become casualties (Hudgens, 1993).

The dynamic world political climate suggests that the threat of a chemical battlefield will continue. Continued attention to such issues has important implications for future equipment design, training, and doctrine regarding operations in NBC-contaminated environments. Research efforts and results from these three programs will help maintain a ready and capable defensive force.

REFERENCES

Blewett, W. K., Arca, V. J., Jones, D. W., Redmond, D. P., Cantwell, D., & Wiley, P. (1995). *A P2NBC2 report: Patient decontamination operations at a corps hospital* (ERDEC Rep. No. TR–229). Aberdeen Proving Ground, MD: U.S. Army Research, Development and Engineering Center. (DTIC No. AD–B198 365)

Blewett, W. K., Arca, V. J., Stickel, G. A., Jones, D. W., & Rowan, W. A. (1990). *P2NBC2 test of battalion aid station operations in NBC conditions* (CRDEC Rep. No. TR–148). Aberdeen Proving Ground, MD: U.S. Army Chemical Research, Development and Engineering Center. (DTIC No. AD–B141 610)

Blewett, W. K., Jones, D. W., & Arca, V. J. (1991). *P2NBC2 report: Helicopter air ambulance operations in a chemical environment* (CRDEC Rep. No. TR–255). Aberdeen Proving Ground, MD: U.S. Army Chemical Research, Development and Engineering Center. (DTIC No. AD–B154 125)

Blewett, W. K., Ramos, G. A., Redmond, D. P., Cadarette, B. S., Hudgens, G. A., Fatkin, L. T., & McKiernan, K. (1994). *P2NBC2 test: The effects of microclimate cooling on tactical performance* (ERDEC Rep. No. TR–148). Aberdeen Proving Ground, MD: Edgewood Research, Development and Engineering Center. (DTIC No. AD–B183 287)

Blewett, W. K., Ramos, G. A., Redmond, D. P., & Fatkin, L. T. (1993). *A P2NBC2 report: Mechanized smoke operations in MOPP-4* (ERDEC Rep. No. TR–122). Aberdeen Proving Ground, MD: Edgewood Research, Development and Engineering Center. (DTIC No. AD–B177 600)

Blewett, W. K., Redmond, D. P., Modrow, H. E., Fatkin, L. T., & Hudgens, G. A. (1994). *P2NBC2 test of smoke/decontamination platoon operations* (ERDEC Rep. No. TR–158). Aberdeen Proving Ground, MD: Edgewood Research, Development and Engineering Center. (DTIC No. AD–B185 581)

Blewett, W. K., Redmond, D. P., Popp, K., Harrah, D. M., Kirven, L., & Banderet, L. E. (1992). *A P2NBC2 report: Detailed equipment decontamination operations* (CRDEC Rep. No. TR–330). Aberdeen Proving Ground, MD: U.S. Army Chemical Research, Development and Engineering Center. (DTIC No. AD–B171 813)

Blewett, W. K., Redmond, D. P., Ramirez, T., & Harrah, D. M. (1993). *A P2NBC2 report: Mobile subscriber equipment operations in a chemical environment* (ERDEC Rep. No. TR–022). Aberdeen Proving Ground, MD: Edgewood Research, Development and Engineering Center. (DTIC No. AD–B172 969)

Blewett, W. K., Seitzinger, A. T., Redmond, D. P., Fatkin, L., & Banderet, L. E. (1993). *A P2NBC2 report: Light division night decontamination operations* (ERDEC Rep. No. TR–087). Aberdeen Proving Ground, MD: Edgewood Research, Development and Engineering Center. (DTIC No. AD–B175 113)

Blewett, W. K., von Fahnestock, F. M., Harris, J. L., Knoebel, E. R., O'Hern, M., Harris, L., Redmond, D. P., Fatkin, L. T., Rice, D. J., & Popp, K. (1995). *A P2NBC2 report: Patient decontamination at mobile medical facilities* (ERDEC Rep. No. TR–255). Aberdeen Proving Ground, MD: Edgewood Research, Development and Engineering Center. (DTIC No. AD–B200 693)

Davis, E. G., Wick, C. H., Salvi, L., & Kash, H. M. (1990). *Soldier performance of military operational tasks conducted while wearing chemical individual protective equipment (IPE): Data analysis in support of the revision of the U.S. Army field manual on NBC protection (FM 3–4)* (BRL Rep. No. TR–3155). Aberdeen Proving Ground, MD: U.S. Army Ballistic Research Laboratory. (DTIC No. AD–A230 157)

Department of the Army. (1987). *Letter of instruction for the assessment of the physiological and psychological effects of the NBC environment and sustained operations on systems in combat (P2NBC2)*. Washington, DC: U.S. Army Deputy Chief of Staff for Operations and Plans.

Department of the Army. (1992). *NBC protection* (Field manual FM 3–4). Washington, DC: Headquarters, Department of the Army.

Draper, E. S., & Lombardi, J. J. (1986). *Combined arms in a nuclear/chemical environment force development testing and experimentation, summary evaluation report phase I.* Fort McClellan, AL: U.S. Army Chemical School.

Headley, D. B., Brecht-Clark, J. M., Feng, T., & Whittenburg, J. A. (1988). *The effects of the chemical defense ensemble and extended operations on performance and endurance of combat vehicle crews* (Tech. Rep. No. 811). Alexandria, VA: U.S. Army Research Institute. (DTIC No. AD–B131 688)

Headley, D. B., Brecht-Clark, J. M., & Whittenburg, J. A. (1989). Sustained operations of artillery crews in NBC and non-NBC environments. *Military Medicine, 154,* 511–515.

Headley, D. B., & Cunningham, D. (1995). *P2NBC2 special report: Annotated bibliography of P2NBC2 field studies, 1985–1994.* Unpublished manuscript, U.S. Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, MD.

Hudgens, G. A. (1993, January). *Evaluation of dropout casualties in P2NBC2 tests: Psychological factors.* Paper presented at the meeting of the P2NBC2 Working Group, U.S. Army Chemical School, Fort McClellan, AL.

Hudgens, G. A., Malkin, F. J., & Fatkin, L. T. (1992). *Stress evaluation of a Special Forces Assessment and Evaluation course* (Tech. Memorandum No. 6–92). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory. (DTIC No. AD–A256 793)

Jarboe, R. L., & Troutman, M. D. (1990). *NBC reconnaissance squad operations* (Rep. No. 89–CEP–0600E). Fort Knox, KY: Test and Experimentation Command. (DTIC No. AD–B141 791L)

Johnson, D. M., & Silver, J. D. (1992). *Stinger team performance during engagement operations in a chemical environment: The effect of cuing* (Tech. Rep. No. 957). Alexandria, VA: U.S. Army Research Institute. (DTIC No. AD–A254 524)

Johnson, D. M., & Silver, J. D. (1993). *Stinger team performance during engagement operations in a chemical environment: The effect of experience* (Tech. Rep. No. 1638). Alexandria, VA: U.S. Army Research Institute. (DTIC No. AD–A268 952)

Johnson, E. M., & Baker, J. D. (1974). Field testing: The delicate compromise. *Human Factors, 16,* 203–214.

McNally, R. E., & Berndt, J. E. (1993). *P2NBC2 Heat Strain Decision Aid user's guide* (Version 2.1). Joppa, MD: Science Applications International Corporation. (DTIC No. AD–A266 072)

Mojecki, J. A., Phillips, W. A., Draper, E. S., Hershberger, R., Studdard, W. C., & Williams, L. G. (1987). *Combined arms in a nuclear/chemical environment (CANE), phase IIA summary evaluation report.* Fort McClellan, AL: U.S. Army Chemical School.

Perez, P. J., & Chaudoin, W. J. (1990). *Tank combat service support and mobility test for physiological and psychological effects of nuclear, biological, and chemical (NBC) and sustained operations on systems in combat (P2NBC2) concept evaluation program (CEP)* (Rep. No. 89–CEP–0600C). Fort Knox, KY: Test and Experimentation Command. (DTIC No. AD– B145 138)

Redmond, D. P. (1993, January). *Evaluation of dropout casualties in P2NBC2 tests: Physiological factors.* Paper presented at the meeting of the P2NBC2 Working Group, U.S. Army Chemical School, Fort McClellan, AL.

Sheroke, R. M., & Klopcic, J. T. (1991). *The Army unit resiliency analysis (AURA) computer simulation model: A brief overview* (BRL Memorandum Rep. No. 3892). Aberdeen Proving Ground, MD: Ballistic Research Laboratory. (DTIC No. AD–A232 951)

Stokes, J. W., & Banderet, L. E. (1997/this issue). Psychological aspects of chemical defense and warfare. *Military Psychology, 9,* 395–415.

Taylor, H. L., & Orlansky, J. (1991). *The effects of wearing protective chemical warfare combat clothing on human performance* (IDA Paper No. P–2433). Alexandria, VA: Institute for Defense Analyses. (DTIC No. AD–A250 716)

Taylor, H. L., & Orlansky, J. (1993). The effects of wearing protective chemical warfare combat clothing on human performance. *Aviation, Space, and Environmental Medicine, 64*(3, Sect. 2), A1–A41.

U.S. Army Chemical School. (1989). *Combined arms in a nuclear/chemical environment (CANE), phase IIB summary evaluation report.* Fort McClellan, AL: U.S. Army Chemical School.

U.S. Army Chemical School. (1993). *Summary evaluation report (SER) for combined arms in a nuclear/chemical environment (CANE) force development test & experimentation (FDTE): Close combat light (CCL).* Fort McClellan, AL: U.S. Army Chemical School.

U.S. Army TRADOC Analysis Command. (1992). *JANUS(A) and Brigade/Battalion Simulation (BBS) Cost and Training Effectiveness Analysis (CTEA)* (TRAC–WSMR–CTEA Rep. No. 92–006). White Sands Missile Range, NM: TRADOC Analysis Command. (DTIC No. AD–B186 373)

U.S. General Accounting Office. (1991). *Chemical warfare: Soldiers inadequately equipped and trained to conduct chemical operations* (Rep. No. GAO/NSIAD–91–197). Washington, DC: U.S. General Accounting Office.

Zubal, O., Doss, N. W., Faughn, J. A., Kysor, K. P., Szlyk, P. C., Caretti, D. M., & Sils, I. V. (1993). *Evaluation of the effect of protective clothing on the ability of self-propelled artillery (M109) crews to conduct and sustain high firing rate missions* (Rep. No. ARL–MR–98). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory. (DTIC No. AD–B175 196)

Zubal, O., Doss, N. W., & Thompson, J. L. (1996). *Assessment of towed artillery (M198) crew performance in NBC protective clothing* (Rep. No. ARL–MR–309). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory. (DTIC No. AD–B209 372)